Advancements in AGN, Galaxy Cluster and IGM Research

Jointly organised by Central University of HImachal Pradesh & IUCAA Pune

"Comparative study of flux and color variability of NLSY1 and BLSY1 galaxies using ZTF survey"

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What are Active Galactic Nuclei (AGN)?

AGNs are galaxies whose nucleus (Central Core) produces huge amount of radiation that it even suppresses the radiation output of the rest galaxy. AGNs are up to many thousand times more luminous than the entire Milky Way; energy released within a region approx. the size of our solar system!

Reason of such tremendous radiation output:

AGN have a supermassive black hole at their center, which is actively accreting matter from its surroundings. This accretion process releases a tremendous amount of energy and is the source of the AGN's luminosity.

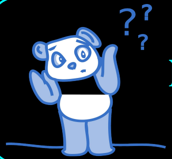
Classification of AGN

AGNs are classified as:

- **Seyfert Galaxy (Type I and II)**
- **Quasars**
- **BL Lacs**
- **Radio Galaxies**

The study of various types of Active Galactic Nuclei (AGN) is of paramount importance:

- Provide insight about the fundamental principles that govern black hole physics, accretion and the effects of the AGN on its host galaxies.
- By understanding the diversity of AGN, we are able to piece together the intricate narrative of galaxy formation, from the beginning of the universe to the modern age.



Now question arises that does these different AGNs are different as an object or something else?

Unified AGN Model

- Unified models of AGN unite all these classes of objects by proposing that they are really a single type of physical object, just observed under different conditions.
- The currently favored model is an 'orientation-based unified model' meaning the differences arise simply because of the different orientations seen by the observer.

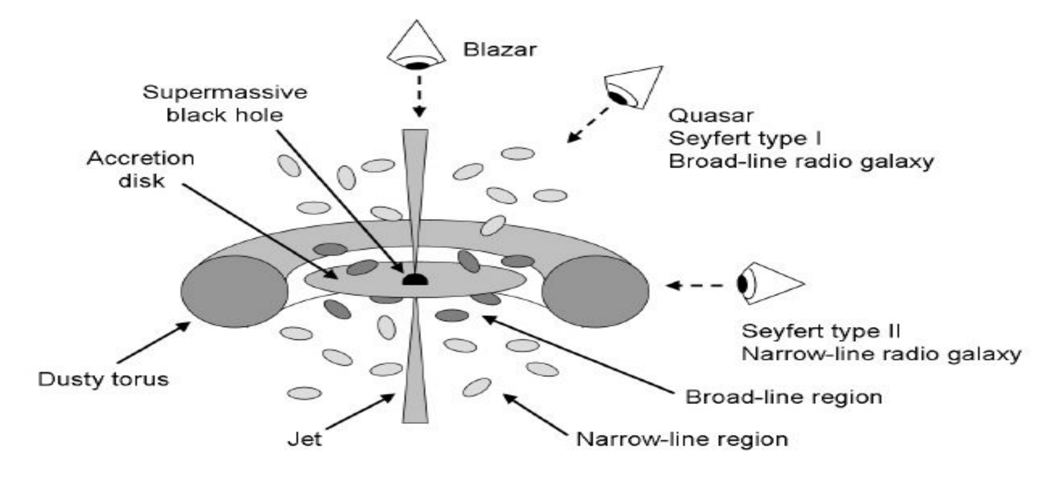
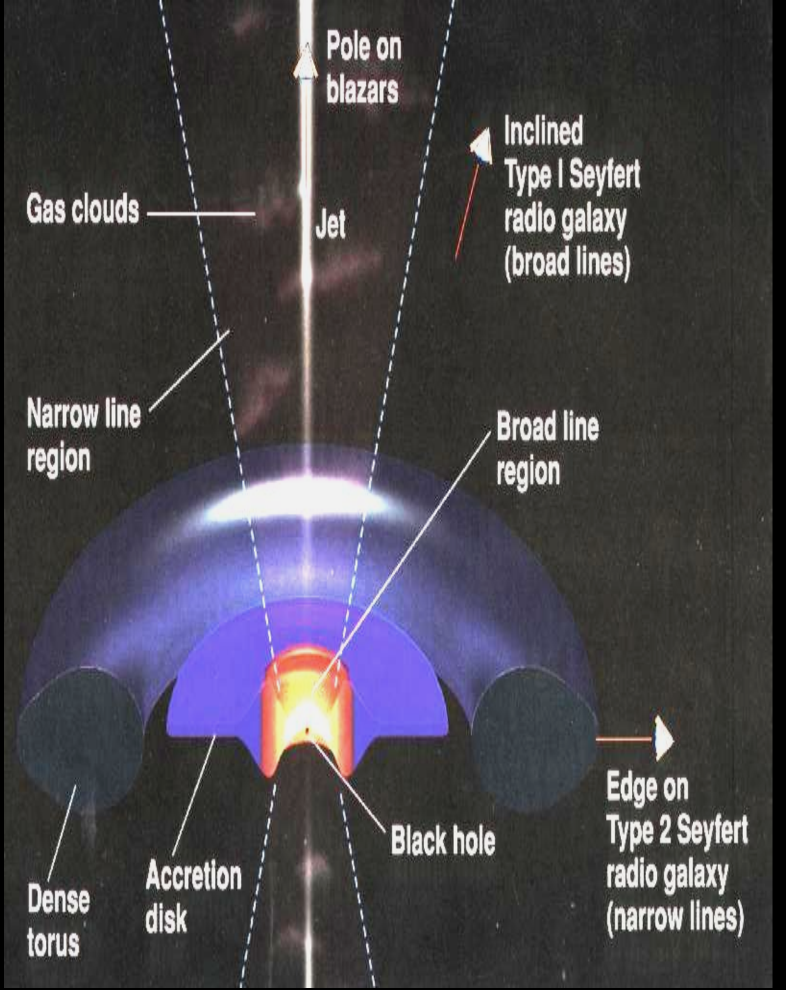


Image Source: https://www.researchgate.net/figure/The-geometry-of-the-AGN-assumed-in-unified-models-where-the-classifica-tion-of-the_fig4_237788999



ImageSource:https://homepages.uc.edu/~hansonmm/ASTRO/LECTURENOTES/W07/Galaxies/Page9.html

Motivation Behind Work

Seyfert 1 sources are really important in AGN's study as it provide the direct observation to study the innermost region of AGN. Here are some of the main reasons why we should look into them:

- **Probing the Nature of AGN:** Studying the emission lines allows us to gain insights into the underlying physics and radiation mechanisms driving AGN.
- **Revealing the Accretion Disk:** The broad emission lines are associated with an accretion disk. By studying these lines, we are able to better know the geometry, the size, and the temperature of the accretion disk.
- **Probing the Innermost Regions:** The Seyfert 1 galaxies offer a unique opportunity to explore the immediate region around the supermassive black hole.

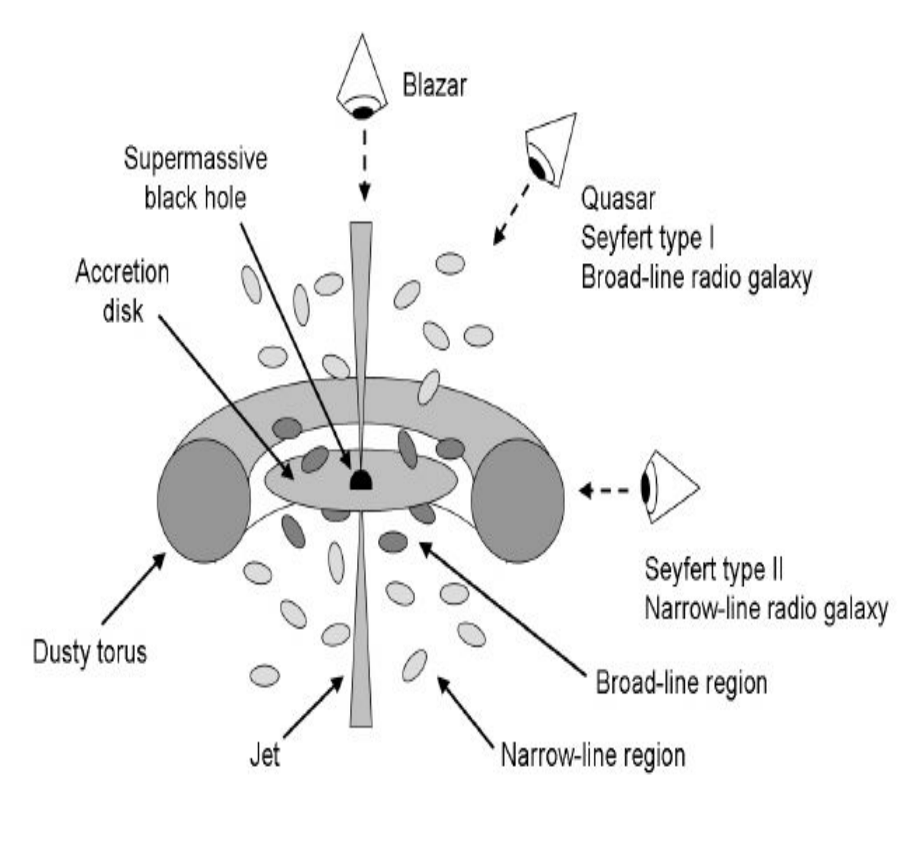


Image Source: https://www.researchgate.net/figure/The-geometry-of-the-AGN-assumed-in-unified-models-where-the-classifica-tion-of-the_fig4_237788999

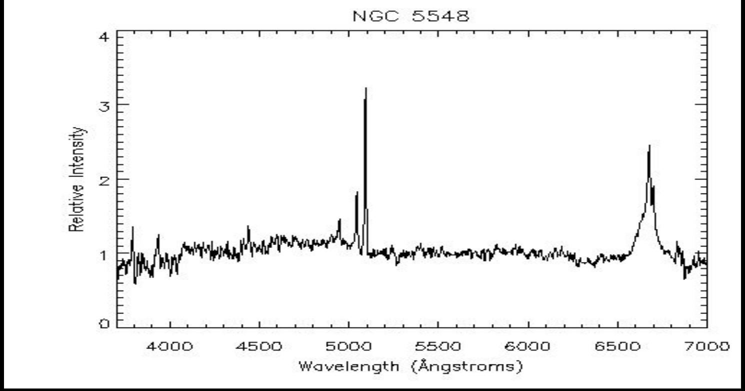
Seyfert Galaxy

- Lower-luminosity AGN
- normally found in spiral galaxies.

Two subclasses:

- Type 1 Seyfert galaxies have two sets of emission lines in their spectra:
  • Narrow lines, with a width (measured in velocity units) of several hundred km/s
  • Broad lines, with widths up to thousands of km/s.

- Type 2 Seyfert galaxies: As Type 1, but with only the narrow line component



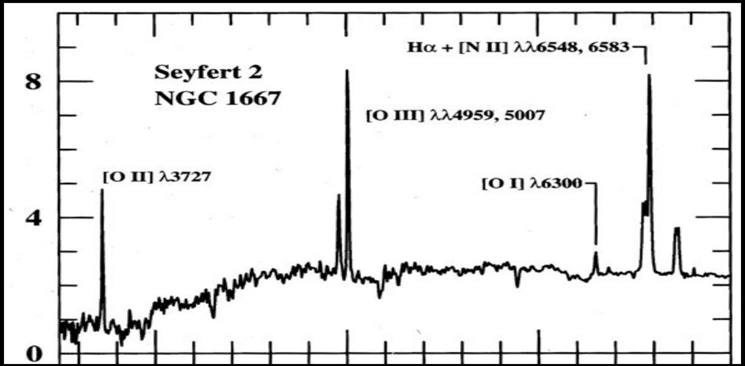


Image Source: https://ned.ipac.caltech.edu/level5/Glossary/Essay_seyfert.html

Seyfert Galaxy

- Lower-luminosity AGN
  - Normally found in spiral galaxies.

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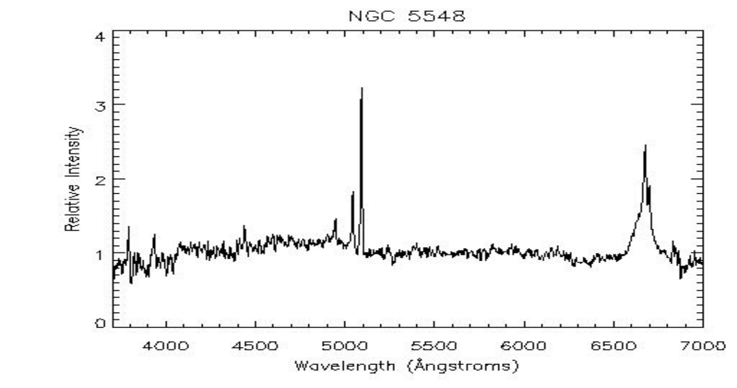


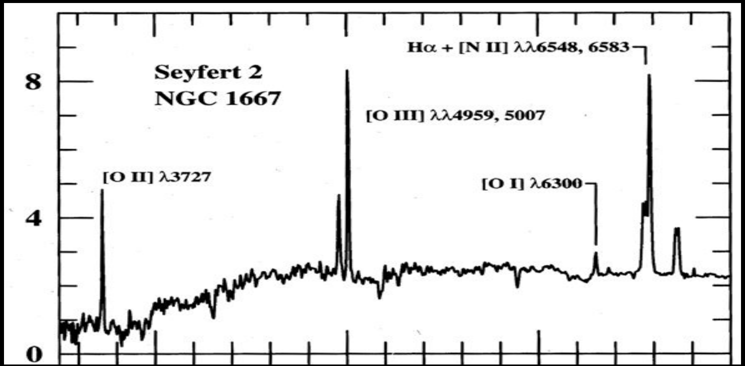


Image Source: https://ned.ipac.caltech.edu/level5/Glossary/Essay_seyfert.html

Narrow Line Seyfert 1 Galaxies:

- **NLS1 galaxies are defined by the narrowness of their Balmer emission lines (FWHM(Hβ) < 2000 km/s) and the relative weakness of the [OIII]λ5007 emission ([OIII]/Hβ_totl < 3).**
- **NLS1 galaxies typically show smaller Balmer lines, stronger FeII emission, and smaller ratios of [OIII]/Hβ_totl compared to broad-line Seyfert 1 (BLS1) galaxies.**
- **Evidence suggests that NLS1 galaxies tend to have smaller black hole masses compared to BLS1 galaxies.**
- **NLS1 galaxies reside in environments similar to BLS1 galaxies and tend to have smaller host galaxies.**
- **They exhibit lower radio-loudness compared to BLS1 galaxies, with only a small fraction showing significant radio emission.**

S. Komossa [2007]

Sample Selection

- We have used the Rakshit's catalogue of Narrow Line Seyfert 1 Galaxies which has 11101 NLSy1.
- Check the light curve availability of NLSy1 sources in the ZTF DR18 and we found the:

r-band light curves	g-band light curves
6475	5401

- Found 5374 NLSy1 sources which are present in both r and g band.
- For Flux Variability:

$$\sigma = \sqrt{\Sigma^2 - \epsilon^2} \;\; if\, \Sigma > \epsilon$$
$$= 0 \qquad otherwise$$

Where, σ is Variability Amplitude

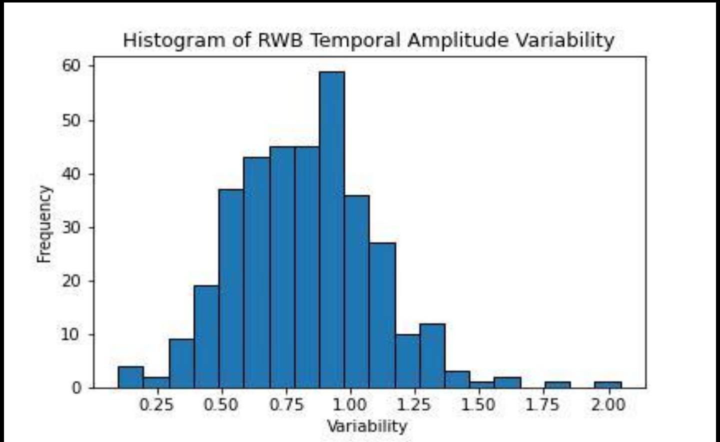
$$\sum = \sqrt{\frac{1}{n-1} \Sigma_{i=1}^{n} \left(\frac{m_i - < m >_i}{} \right)^2}$$

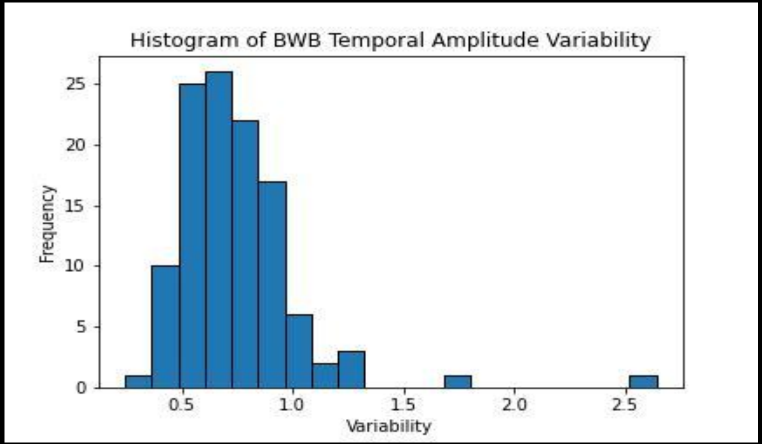
$$\epsilon^2 = \frac{1}{N} \left\{ \sum_{i=0}^{N} \epsilon_i^2 \right\}$$

- To select high variable source we have taken sources with amplitude variability >3% of magnitude (i.e median value).
- High variability sources we get: 2687 sources
- We use the quasi-simultaneous light curve of 2687 NLSy1 with an epoch difference of 0.5 hour, to quantify their color variability.
- These high variability sources shows color variability trend as:

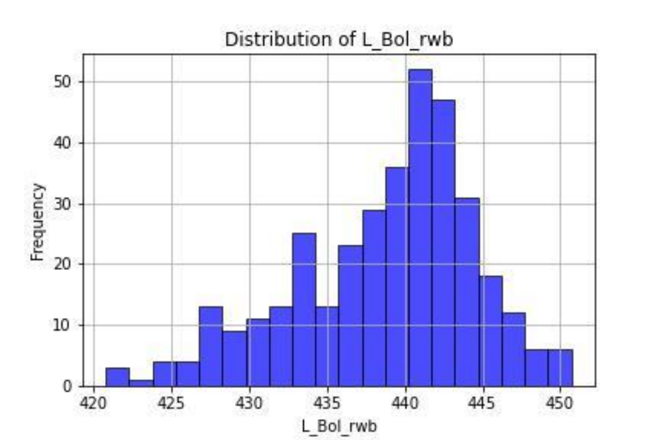
Redder when Bright (RWB)	**Bluer when Brighter (BWB)**
75.8% (356)	24.2% (114)

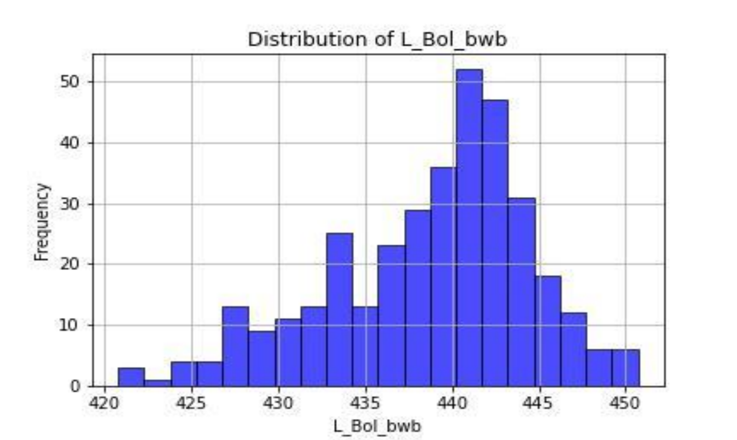
- Amplitude of Temporal Variability $\psi = \sqrt{(A_{\max} - A_{\min})^2 - 2\sigma^2}$





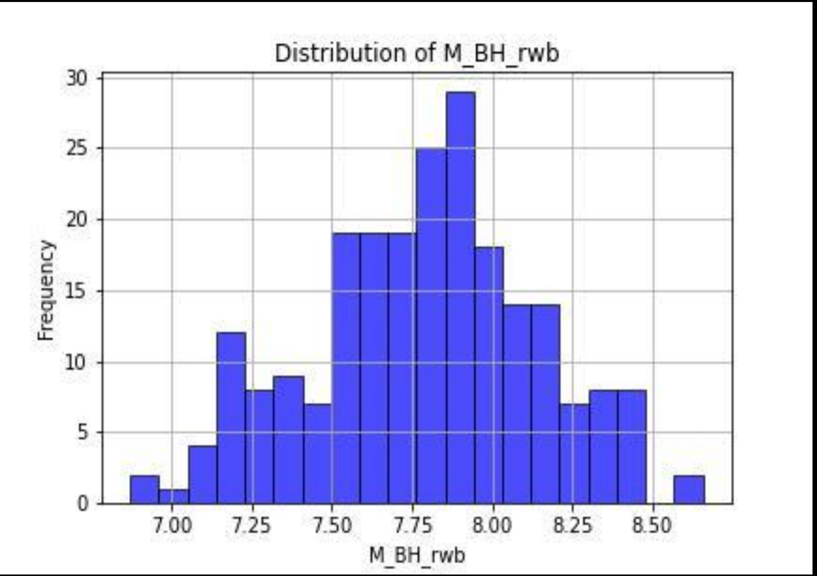
- KS Test between Temporal Amplitude Variability of RWB & BWB:
  K-S Statistics: 0.2128
  P value: $6.4*10^{-4}$
  KS Test clearly suggest that the variability amplitude distribution of BWB and RWB sources are significantly different.
- Distribution of bolometric luminosity in RWB and BWB:

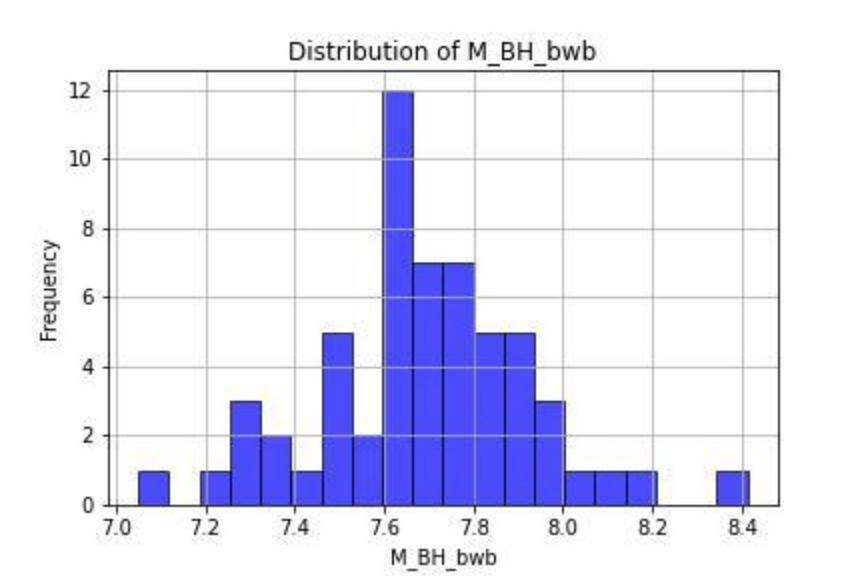




KS Test Result: KS Statistics: 0.1665
P value: 0.0143

- Distribution of Mass of Black Hole in RWB & BWB:

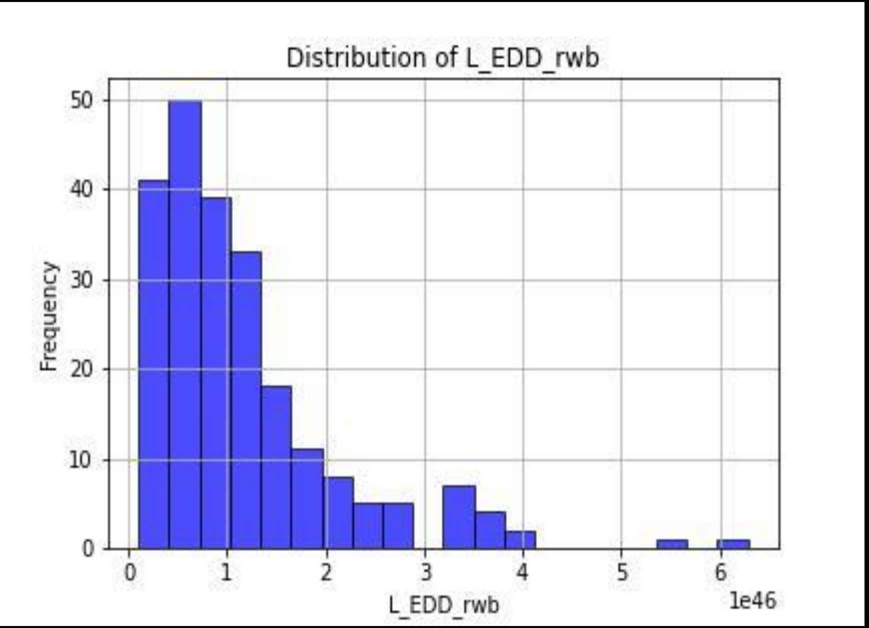


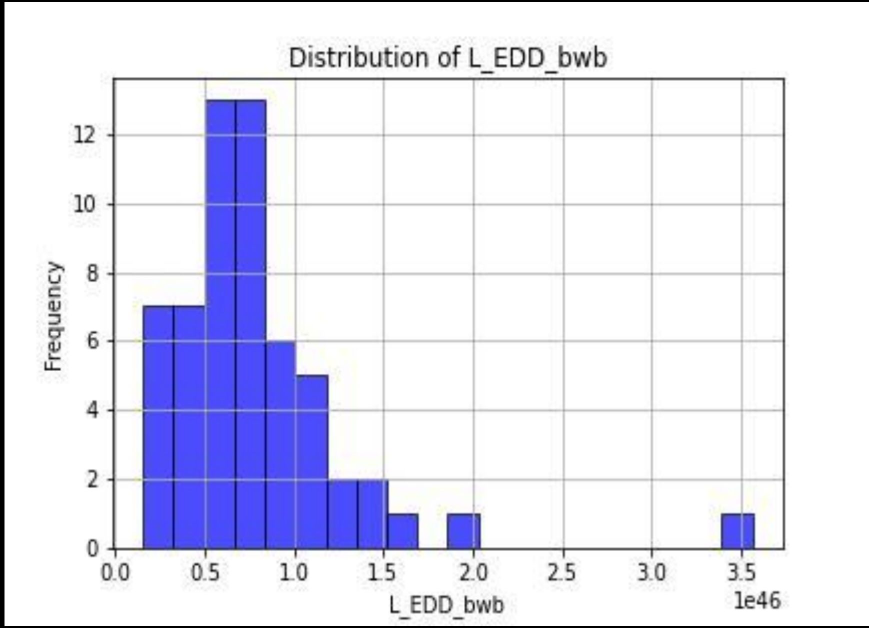


KS Test Result:

KS Statistics: 0.18453
P value: 0.0748

- Distribution of Eddington Luminosity in RWB & BWB:

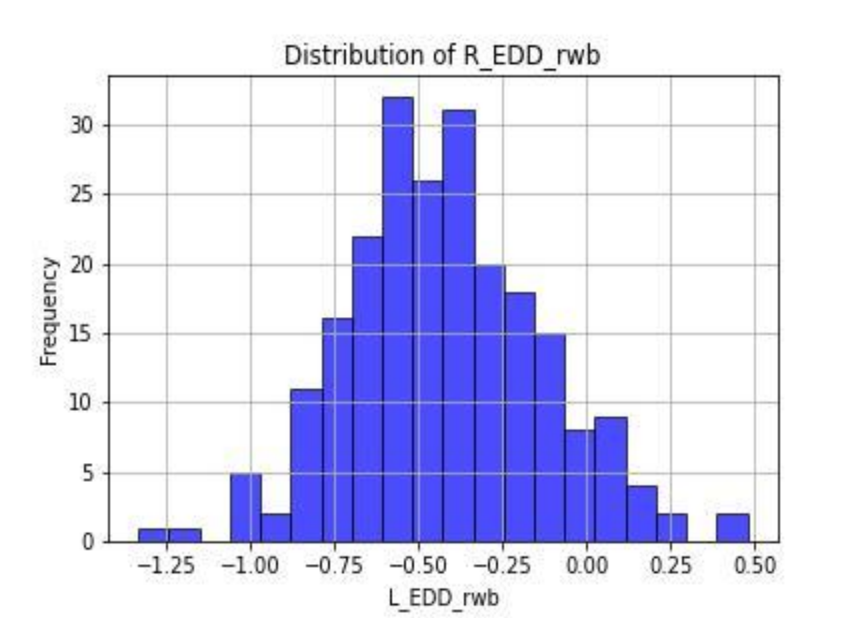


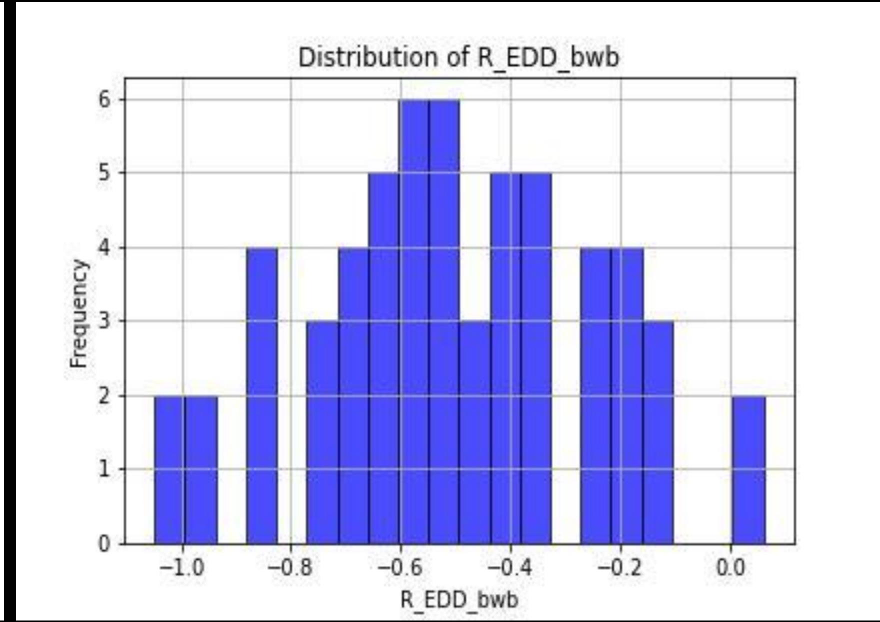


KS Test Result:

KS Statistics: 0.2903
P value: $6.1*10^{-4}$

- Distribution of Eddington Ratio in RWB & BWB:



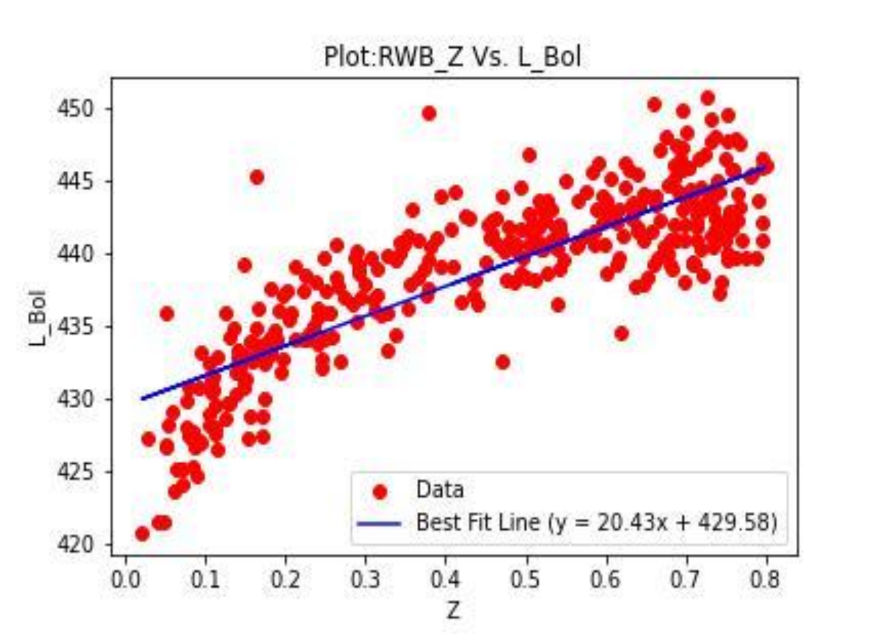


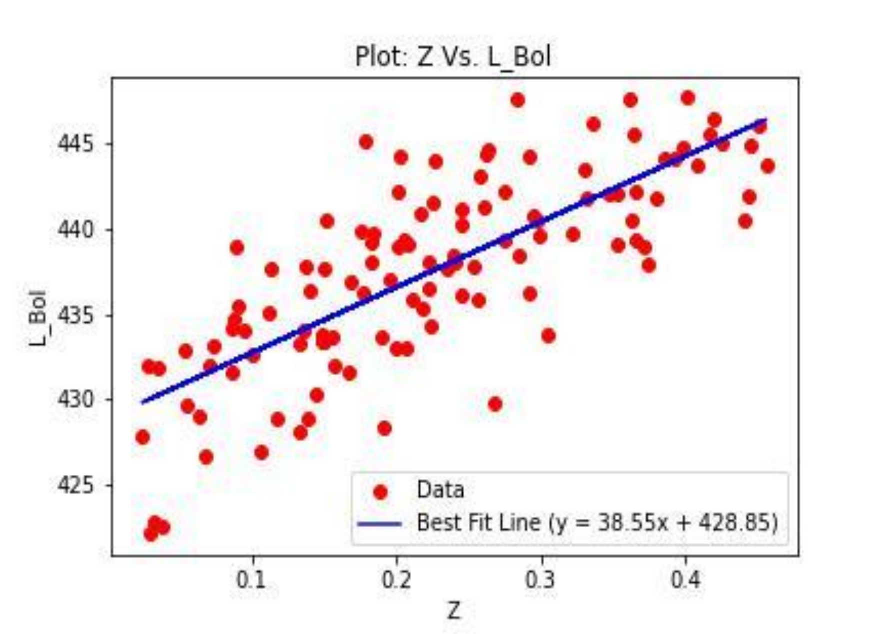
KS Test Result:

KS Statistics: 0.2896

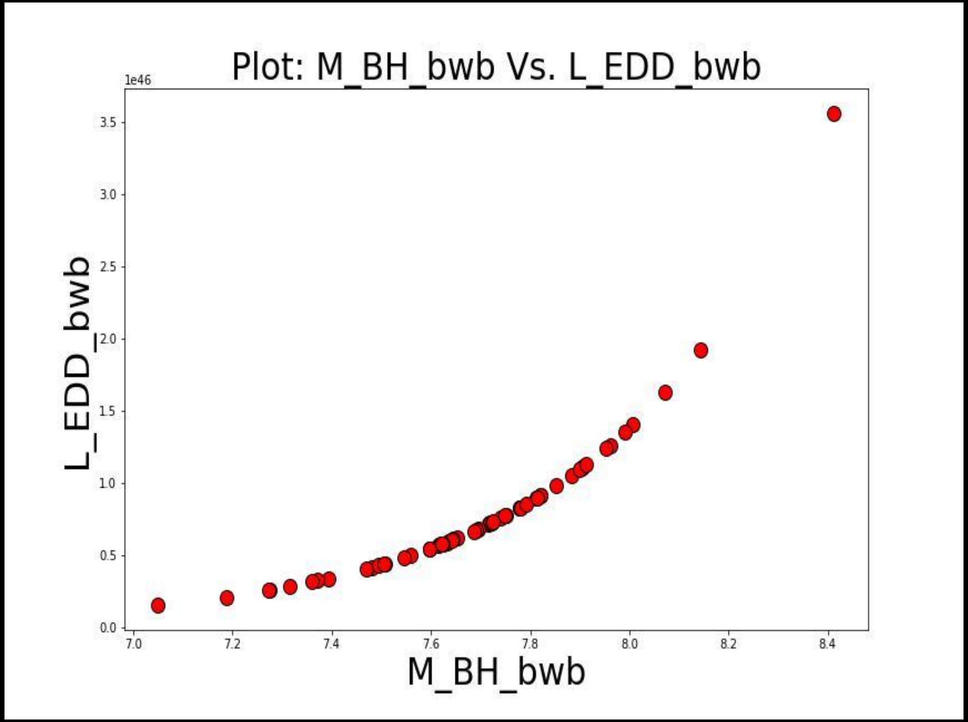
P value: $6.4*10^{-4}$

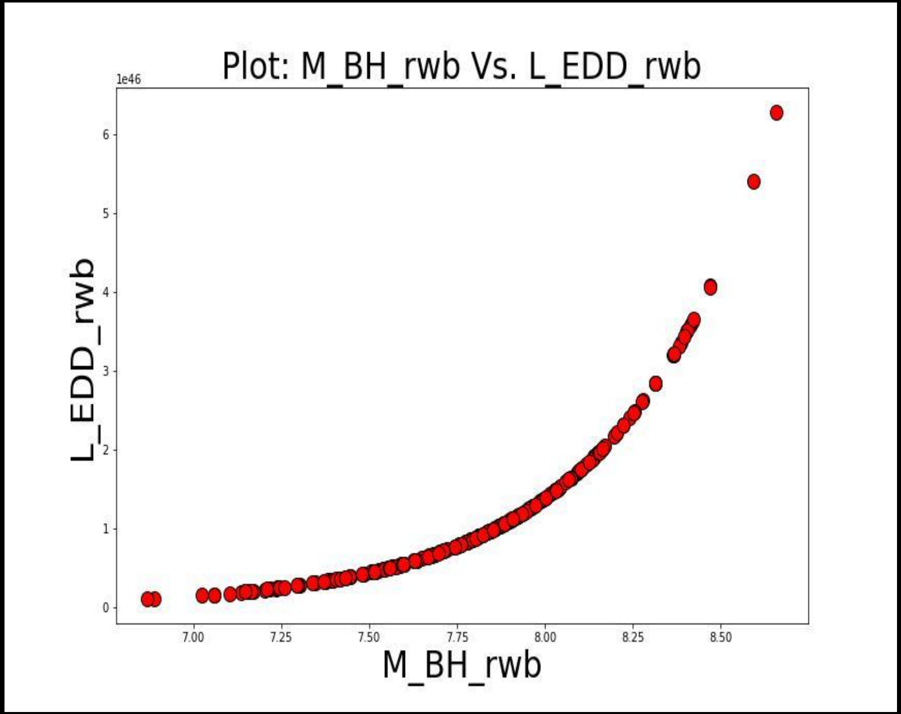
Z Vs. L_{Bol}


Plot:RWB_Z Vs. L_Bol
L_Bol
Z
Data
Best Fit Line (y = 20.43x + 429.58)

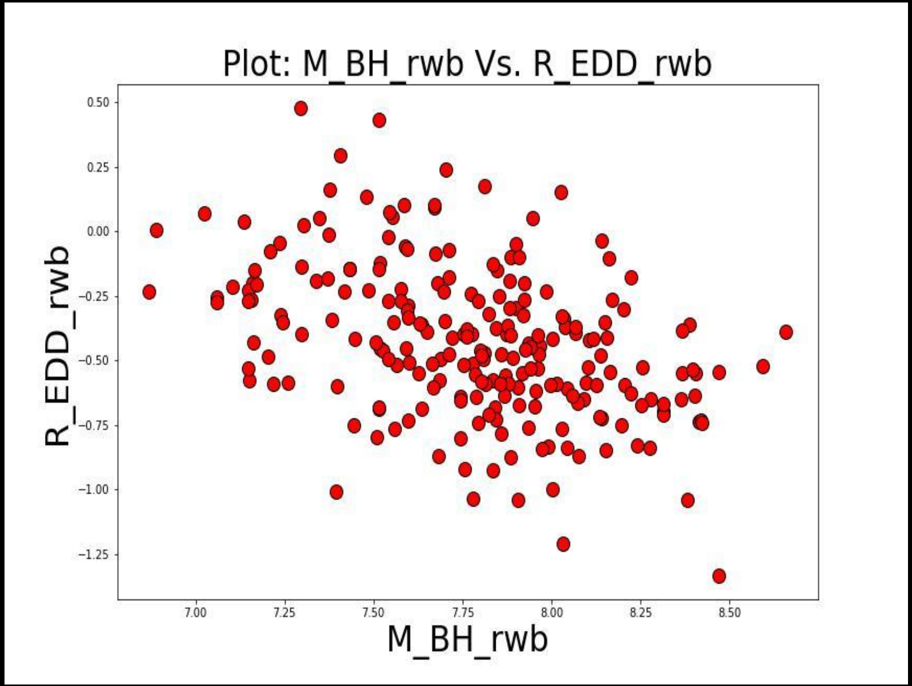

Plot: Z Vs. L_Bol
L_Bol
Z
Data
Best Fit Line (y = 38.55x + 428.85)

M_{BH} Vs. L_{EDD}

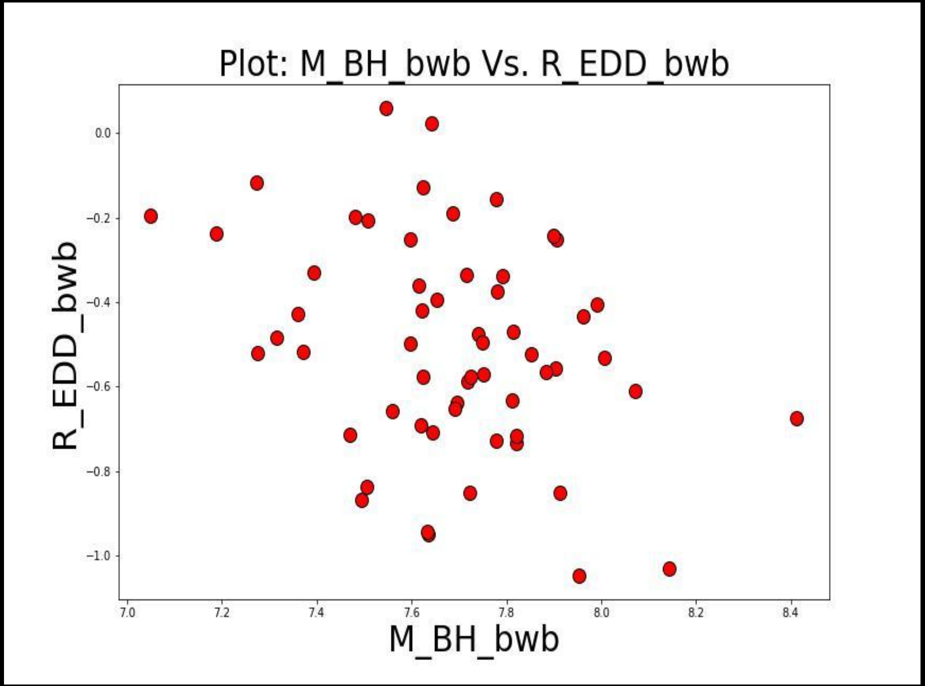

Plot: M_BH_bwb Vs. L_EDD_bwb
1e46
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
L_EDD_bwb
7.0
7.2
7.4
7.6
7.8
8.0
8.2
8.4
M_BH_bwb


Plot: M_BH_rwb Vs. L_EDD_rwb
1e46
6
5
4
3
2
1
0
L_EDD_rwb
7.00
7.25
7.50
7.75
8.00
8.25
8.50
M_BH_rwb

M_{BH} Vs. R_{EDD}



Plot: M_BH_rwb Vs. R_EDD_rwb
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
−1.25
R_EDD_rwb
7.00
7.25
7.50
7.75
8.00
8.25
8.50
M_BH_rwb



Plot: M_BH_bwb Vs. R_EDD_bwb
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
R_EDD_bwb
7.0
7.2
7.4
7.6
7.8
8.0
8.2
8.4
M_BH_bwb

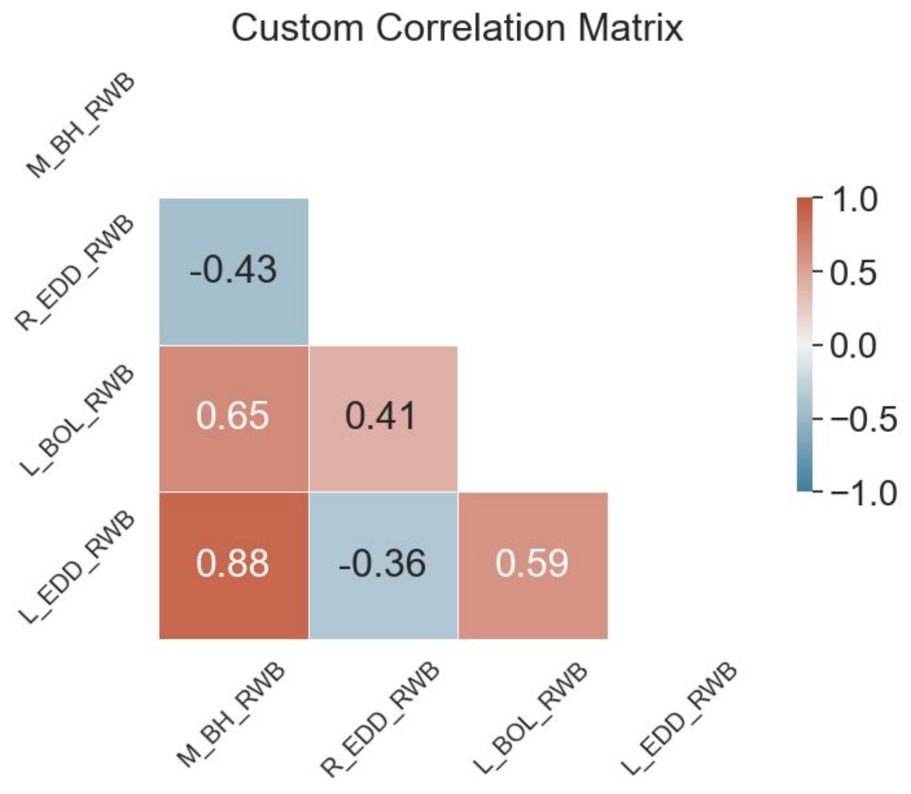
Pearson Correlations:

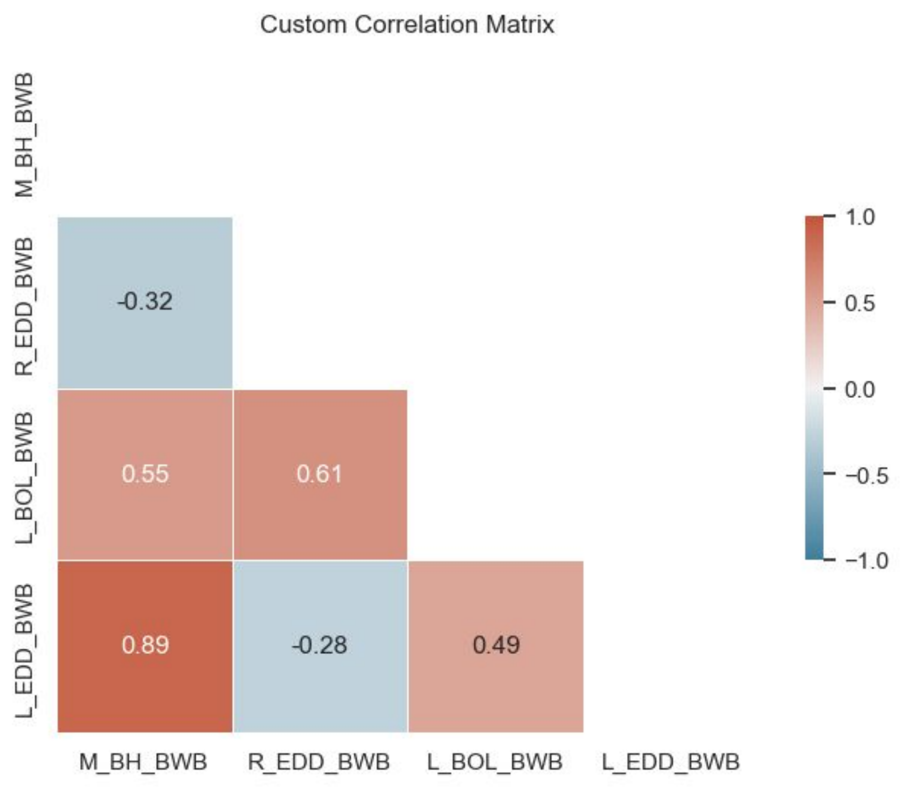
M_BH_RWB	R_EDD_RWB	-0.43
M_BH_RWB	L_BOL_RWB	0.65
M_BH_RWB	L_EDD_RWB	0.88
R_EDD_RWB	L_BOL_RWB	0.41
R_EDD_RWB	L_EDD_RWB	-0.36
L_EDD_RWB	L_BOL_RWB	0.59

Pearson Correlations:

M_BH_BWB	R_EDD_BWB	-0.32
M_BH_BWB	L_BOL_BWB	0.55
M_BH_BWB	L_EDD_BWB	0.89
R_EDD_BWB	L_BOL_BWB	0.61
R_EDD_BWB	L_EDD_BWB	-0.28
L_EDD_BWB	L_BOL_BWB	0.49

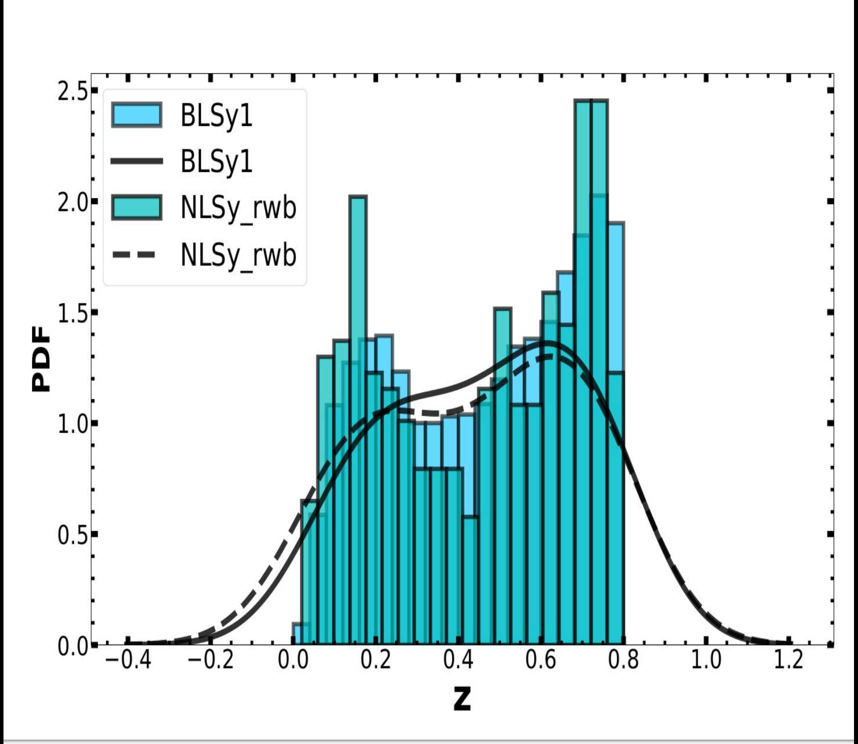
Correlation Matrices

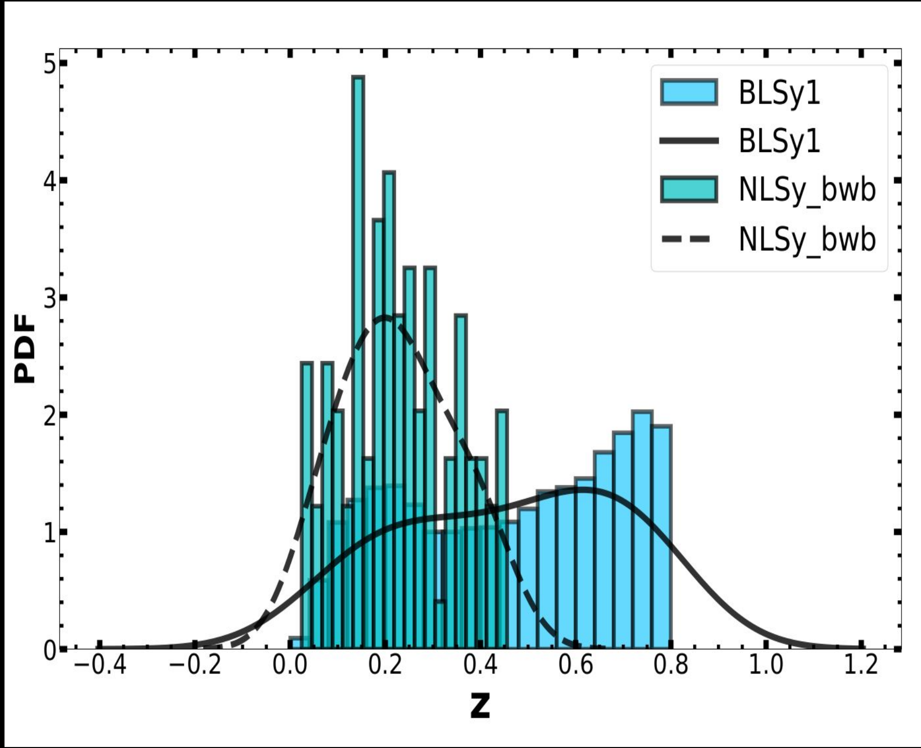




Control Sample for Broad Line Seyfert Galaxies (BLSy1)

- **Used Rakshit's Catalogue of 14885 BLSy1 galaxies .**

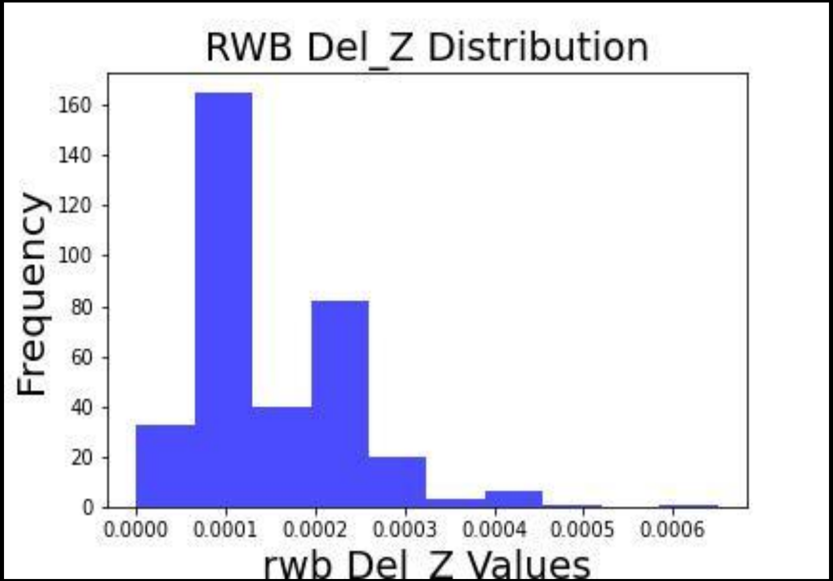


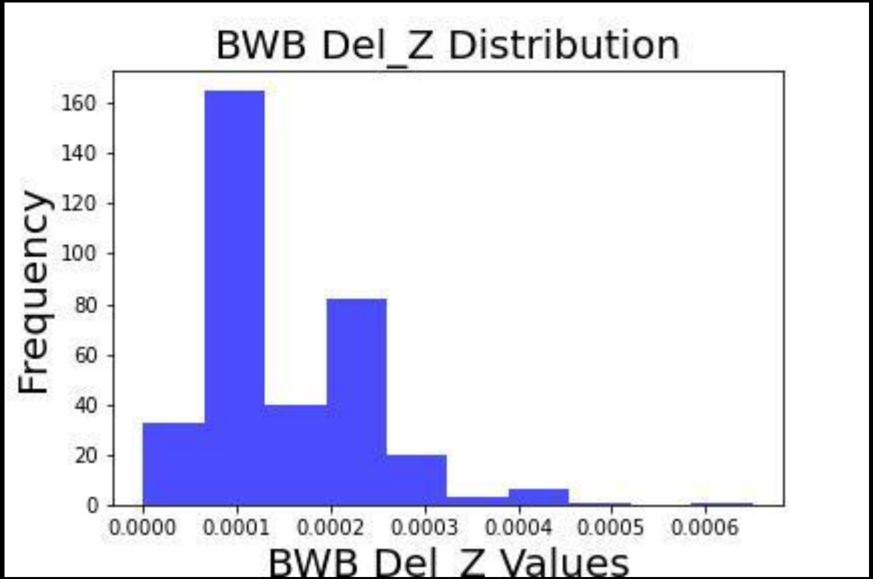


- To make our control sample for BLSy1 we have used condition:

$$|z_{NLSy1} - z_{BLSy1}| < 0.001$$

- Using this condition we get Delta Z distribution corresponding to RWB NLSy1 and BWB NLSy1 as





- **Color variability of BLSy1 galaxies:**

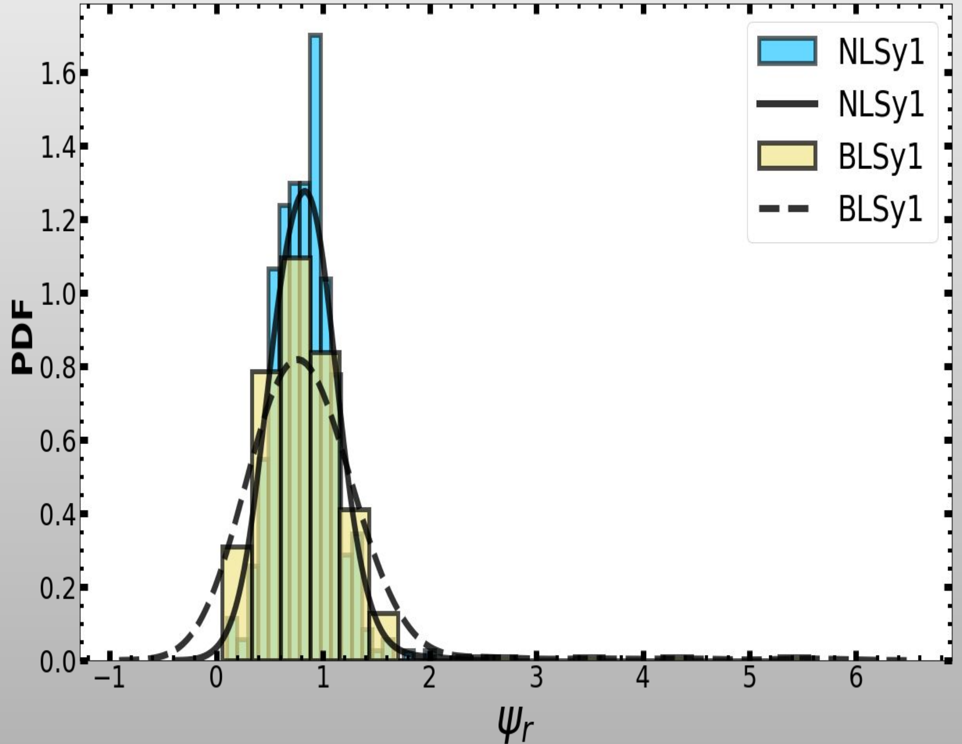
Corresponding to RWB NLSy1, we get

RWB BLSy1	BWB BLSy1
47.25% (291)	52.75% (325)

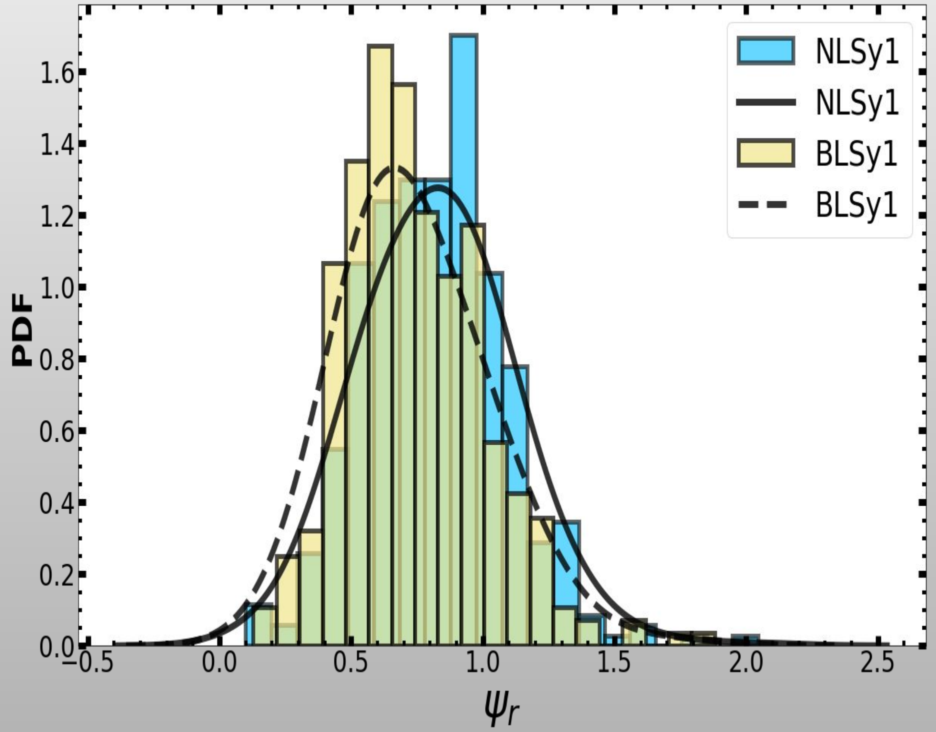
Corresponding to BWB NLSy1, we get

RWB BLSy1	BWB BLSy1
23% (66)	77% (221)

Temporal Amplitude Variability Curve of BLSy1_RWB & BWB Sources Corresponding to NLSy1_RWB Sources

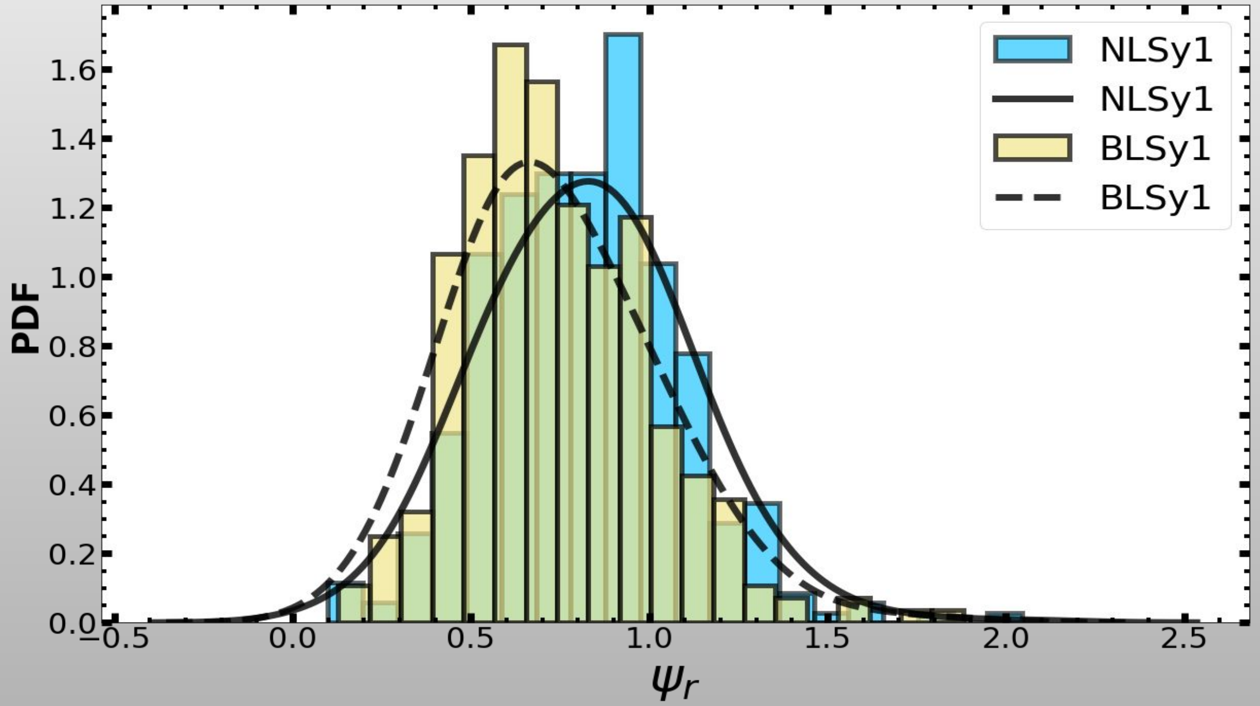


Median Values: NLSy1_RWB: 0.825
BLSy1_RWB: 0.78



Median Values: NLSy1_RWB: 0.825
BLSy1_BWB: 0.695

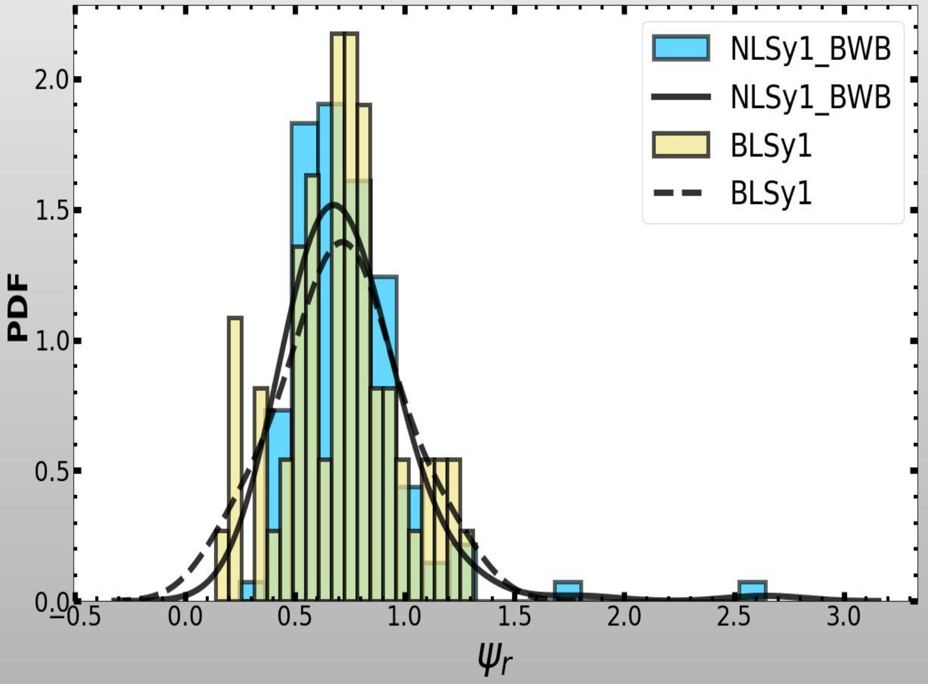
Temporal Amplitude Variability Curve of BLSy1_BWB Sources Corresponding to NLSy1_RWB Sources

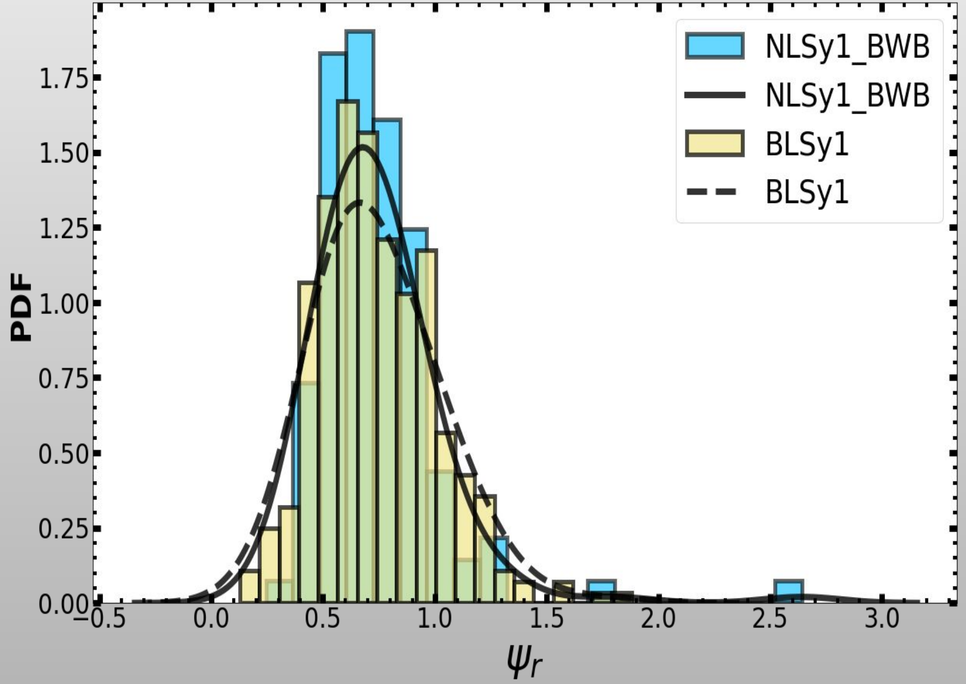


Median Values: NLSy1_RWB: 0.825

BLSy1_BWB: 0.695

Temporal Amplitude Variability Curve of BLSy1_RWB & BWB Sources Corresponding to NLSy1_BWB Sources

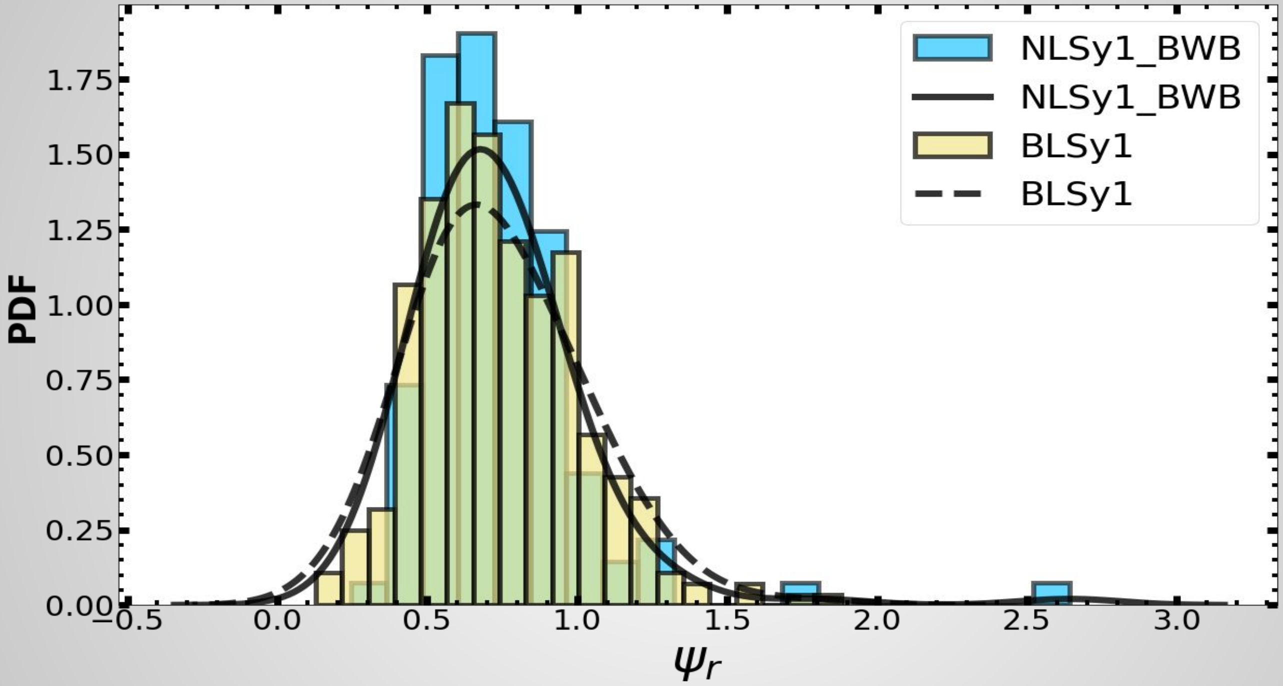




Median Values: NLSy1_BWB: 0.697
BLSy1_RWB: 0.717

Median Values: NLSy1_BWB: 0.697
BLSy1_RWB: 0.695

Temporal Amplitude Variability Curve of BLSy1_BWB Sources Corresponding to NLSy1_BWB Sources



Median Values: NLSy1_BWB: 0.697

BLSy1_RWB: 0.695

Results & Conclusions:

- For BLSy1 galaxies, we get almost opposite trend of RWB & BWB as compared to NLSy1 Galaxies. For NLSy1 galaxies we have results as such:

Redder when Bright (RWB)	Bluer when Brighter (BWB)
75.8% (356)	24.2% (114)

Possible Scenario behind more BWB trend in BLSy1:

The BWB trend in BLSy1 galaxies can be attributed to the dynamism of the accretion disk. Here it has higher accretion rate , causing the inner disk to become hotter and showing the BWB trend. This trend gives insights into the energetic processes occurring in the immediate vicinity of supermassive black holes.

Results & Conclusions:

- **For BLSy1 galaxies, we get almost opposite trend of RWB & BWB as compared to NLSy1**

RWB NLSy1 75.8%(356)
- **BWB BLSy1 52.75%(325)**
- **RWB BLSy1 47.25%(291)**

BWB NLSy1 24.2%(114)
- **BWB BLSy1 77%(221)**
- **RWB BLSy1 23%(66)**

For NLSy1 Galaxies:

Redder when Bright (RWB)	Bluer when Brighter (BWB)
75.8% (356)	24.2% (114)

For BLSy1 Galaxies

Redder when Bright (RWB)	Bluer when Brighter (BWB)
39.5% (357)	60.5% (546)

Possible Scenario behind more BWB trend in BLSy1:

The BWB trend in BLSy1 galaxies can be attributed to the dynamism of the accretion disk. Here it has higher accretion rate , causing the inner disk to become hotter and showing the BWB trend. This trend gives insights into the energetic processes occurring in the immediate vicinity of supermassive black holes.

Possible Scenario behind more RWB trend in NLSy1:

The possible scenario may be behind this is that here in NLSy1 galaxies jets are in very initial starting stage where they are not fully developed so here we get more contribution from thermal emission from the accretion disk.

Future Work

- Our future work will focus on justifying our results with appropriate physical mechanism.

Thank you all.......!

for being a patient audience

Contact: madhu.92265sudan@gmail.com

Broad Band SED Fitting of Source 4c11.69